Physics 129 A
Fall 2004
Professor Freedman
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Final Examination

True-false questions: (+2 for correct answers, -1 for incorrect answers)

1. The correct explanation for the short range of the weak force is that the intermediate weak vector-bosons are heavy.

2. At low energies the quarks inside hadrons appear to be free but at high energies they act like bound particles because of confinement.

3. The ground state of the deuteron must have total isospin of unity because there is no corresponding bound state of two neutrons.

4. For neutral kaon regeneration experiments to work i.e. to produce K_S in a pure K_L beam, the regenerator material should be made of ordinary matter and not an equal mixture of matter and antimatter.

5. The quark mixing matrix (CKM matrix) and the neutrino-mixing matrix (sometimes called the MNSP matrix) are almost identical in terms of the size of corresponding elements because of quark-lepton symmetry.

6. Right now the only experimental evidence that neutrinos have finite mass comes from neutrino oscillation experiments.

7. The naive quark-model explanation for why the neutron is heavier than the proton is that the down quark is heavier than the up quark.

8. The quantity $x = -q^2/2Pq$ is a useful quantity for describing deep inelastic scattering because it represents the momentum transfer.

9. One way to search for the Z^o in hadron-hadron collisions is to consider the number of pairs of positive and negative muons as a function of the dot product of their four momentum and search for a peak in the distribution.

10. Charmonium structure involves more relativistic effects than positronium because the charm quark is much heavier than the electron.

Short Answer Problems:

1. Briefly give the physical reasons for the terms proportional to $A^{2/3}$ and the term proportional to $(A-2Z)^2/A$ in the semi-empirical mass formula for nuclei. Write down the entire formula (you do not need to give the numerical values of the coefficients but state the order of magnitude).

2. Collider facilities were invented to get the maximum energy in the center-of-momentum frame to enable particle production. How much energy would be necessary for a positron beam colliding with an electron at rest to have the center-of-momentum frame energy of colliding electrons and positrons each with 15 GeV?

3. The J/Ψ is seen as a narrow resonance at electron-positron colliders despite the fact that with its 1.5 GeV rest mass it could energetically decay to multi pion states. Explain the conservation law that requires the J/Ψ to decay to odd numbers of pions. Even symmetry-allowed decays to pions are suppressed by an empirical rule, the so-called OZI Rule (named after Okubo, Zweig, and Iizuka). What are the possible values of n for the multi-pion decays: $J/\Psi \rightarrow n\pi$? Draw the diagram for three-pion decay and briefly state and explain qualitatively the physics of the OZI rule.

4. Briefly explain why an elementary system with a permanent electric dipole moment can only exist if the time-reversal symmetry is violated. Take the neutron as a concrete example to discuss.

5. There are no flavor-changing neutral currents (experimentally it was first found that there are not strangeness changing neutral currents). What does this statement mean for the Z^o, i.e. what kinds of elementary fermions and anti fermions does a Z^o produce? The mechanism that prevents flavor changing neutral currents in the Standard Model is called the GIM mechanism (after Glashow, Iliopoulos and Maiani). What is the minimum number of quark flavors required for the GIM mechanism to work? Briefly explain the GIM mechanism.

1. Particle A, at rest decays into three or more particles:
$A \rightarrow B + C + D + \cdots$
(a) Determine the maximum and minimum energies that B can have in terms of the masses of the various masses involved in the decay process.
(b) Find the maximum and minimum electron energy in muon decay: $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$.

2. (a) Sketch the lowest-order Feynman diagram for $\gamma + \gamma \rightarrow \gamma + \gamma$ in ordinary QED (only particles are electrons, positrons and photons).
(b) What order of α is the cross section for this process?
(c) If you consider all of the particles of the Standard Model, and considering only the topology of the diagram in part (a), discuss what new possibilities are available.
(d) It turns out that the diagram in (a) in ordinary QED makes the largest contribution to the cross section. Explain why.

3. (a) Draw the lowest order two lowest-order diagrams for the process of electron positron scattering, called "Bhabha scattering".
(b) Determine the mass of the virtual photon in each of the diagrams assuming that the electron and the positron are at rest. What is the velocity of the photon.
(c) Obviously the photons involved here are not real photons. Explain the physics of what is going on.

4. What is the total isospins for the following reactions: (a) $\bar{K}^0 + p \rightarrow \Sigma^+ + \pi^0$
(b) $K^- + p \rightarrow \Sigma^+ + \pi^-$. Find the ratio of the two cross sections, assuming one or the other isospin channel dominates.

5. Consider the decay of the neutron with spin ½ into a proton, an electron and an antineutrino. We want to estimate the decay probability per unit time using the ideas of Fermi's golden rule.

(a) Write down an expression for Fermi's golden rule and explain the physical meaning of each symbol you use.

Pretend that you do an experiment in which you are able to prepare a sample of neutrons with net polarization represented by the vector $\vec{J}$. In your experiment you are able to measure the momentum of the final state electron $\vec{p}_e$, the electron spin $\vec{\sigma}_e$, and the neutrino momentum $\vec{p}_\nu$. (Extra credit if you explain how you might determine the neutrino momentum.)

(b) It is believed that the decay probability must be a scalar or pseudo-scalar quantity. Explain the implications of this assumption. In other words, "Why do we believe that decay probability can't be a vector or tensor?"

(c) Write down the form of the terms that could be in the decay probability in terms of the experimentally accessible quantities: $\vec{J}$, $\vec{p}_e$, $\vec{p}_\nu$, and $\vec{\sigma}_e$

(d) Discuss the significance of each term in the expression in terms of the discrete symmetries of space and time inversion. In other words which terms could give rise to parity violation and/or time-reversal violation?

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